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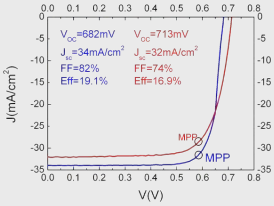
HIGH QUALITY SURFACE PASSIVATION AND HETEROJUNCTION FABRICATION BY VHF-PECVD DEPOSITION OF a-Si:H ON c-Si THEORY AND EXPERIMENTS

Motivation

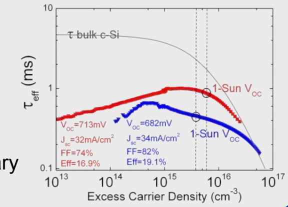
- Reach high V_{oc}-high efficiency with a-Si:H/c-Si heterostructures: need of high quality c-Si surface passivation.
- Investigation of a-Si:H layers passivation properties: analysis of lifetime measurements using an amphoteric model.
- Double side passivating layer structures speed up the development of high efficiency solar cell.

Best Efficiency Solar cells



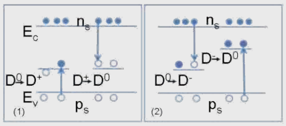
Wafer Type	V_{oc}(mV)	FF	η (%)
n 1Ωcm	682	82	19.1
n 1Ωcm	713	74	16.9
p 0.5Ωcm	690	74	16.3

- High efficiencies are achieved on both p and n-typed c-Si, partially due to high V_{oc}'s
- A trade-off exists between V_{oc} and FF. However, c-Si surface passivation is necessary to achieve high efficiency.



Passivation theory

Modeling interface recombination through amphoteric defects at the a-Si:H/c-Si interface[1].

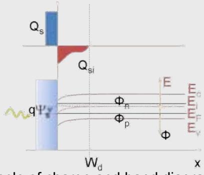


Recombination through amphoteric states: 2 paths coexist.

Deposition of VHF PECVD a-Si:H on c-Si ➔ Surface passivation

- This passivation scheme is based on the recombination through amphoteric defects on a-Si:H, at the a-Si:H/c-Si interface.
  - Dangling bonds at the interface (N_s)➔ Recombination.
  - Average charge density at the interface (Q_s) ➔ Field effect passivation.

(1) S. Olibet, E. Vallat-Sauvain, C. Ballif, *Phys. Rev. B* **76** (2007) 35326.

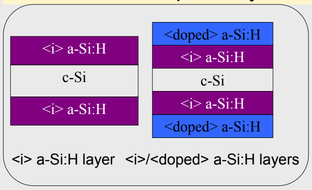


Example of charge and band diagram at the a-Si:H/c-Si interface

From double side passivation…

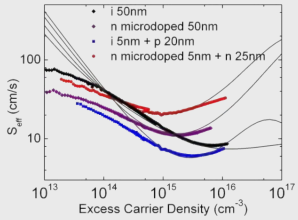
- Effective lifetime (τ_{eff}) measured by QSSPC ➔ injection level (ECD) dependent effective surface recombination velocity S_{eff}.

Example of symmetrical structures on FZ 2.5Ωcm p-type c-Si.



$$S_{eff} = \left(\frac{1}{\tau_{eff}} - \frac{1}{\tau_b}\right)\cdot\frac{W}{2}$$

τ_b bulk lifetime
W wafer width.



Fit to measured S_{eff} for various a-Si:H layer

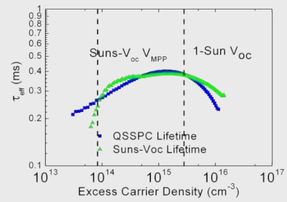
- Symmetrical passivation structures ➔ determine quality of the passivating layer.
- Fitting of S_{eff}(ECD) curves using the physical model.
  - ➢Intrinsic a-Si:H layer ➔ Low N_s.
  - ➢Doped a-Si:H layers ➔ Q_s tuning.
  - ➢Combination of both ➔ Low S_{eff}.
- S_{eff} : down to 6 cm/s with <i> a-Si:H/<p> a-Si:H layers.
- The optimization of the passivation layers is facilitated.

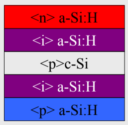
N_s ⇩ Q_s

Sample	Ns (10^9·cm⁻²)	Qs (10^{10}·cm⁻²)
i 50 nm	5.2	-7
n-µdoped 50 nm	53	-85
i 5 nm + p 20nm	3.2	150
n-µdoped 5 nm + n 25nm	40	-50

Fit parameters

…to final solar cell

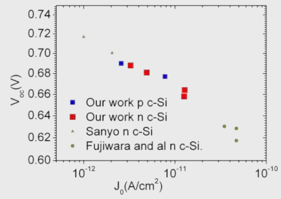




Lifetime measured by QSSPC and Suns-V_{oc} of a solar cell based on previous layers.

- High quality stacked layers allow the fabrication of high V_{oc} solar cells.
  - ➢In this example: V_{oc}= 675mV.
    - ➔ Limited by the <i> a-Si:H/<n> a-Si:H stack.
  - ➢Suns-V_{oc} measurements are made after front and back contact depositions.
    - ➔ To check if the contact deposition damages the a-Si:H passivating layers.

Relation between 1-Sun V_{oc} and J_0



- Dark IV characteristics of the cells are fitted by the 1 diode equation.
- 1-Sun V_{oc} depends on J_0 and n.
- Set of a-Si:H/c-Si solar cells on various c-Si substrates:
  - ➢n constant ≈ 1.2.
  - ➢ln(J_0) is linearly dependent to 1-Sun V_{oc} .
- Dark IV characteristics (J_0): supplementary tool for passivation quality control?

$$J = J_0\left[\exp\left(\frac{qV}{nkT}\right)-1\right] - J_{ph}$$

$$V_{oc} \approx \ln\left(\frac{J_{ph}}{J_0}\right)\times\frac{nkT}{q}$$

J_0: saturation current density
J_{ph}: photogenerated current density
n: diode ideality factor

Conclusion

- Development of deposited a-Si:H layers is facilitated by analysis of the passivation property using an amphoteric model.
- Solar cells benefit from the development of these passivating layers, resulting in V_{oc} and efficiency improvement.

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